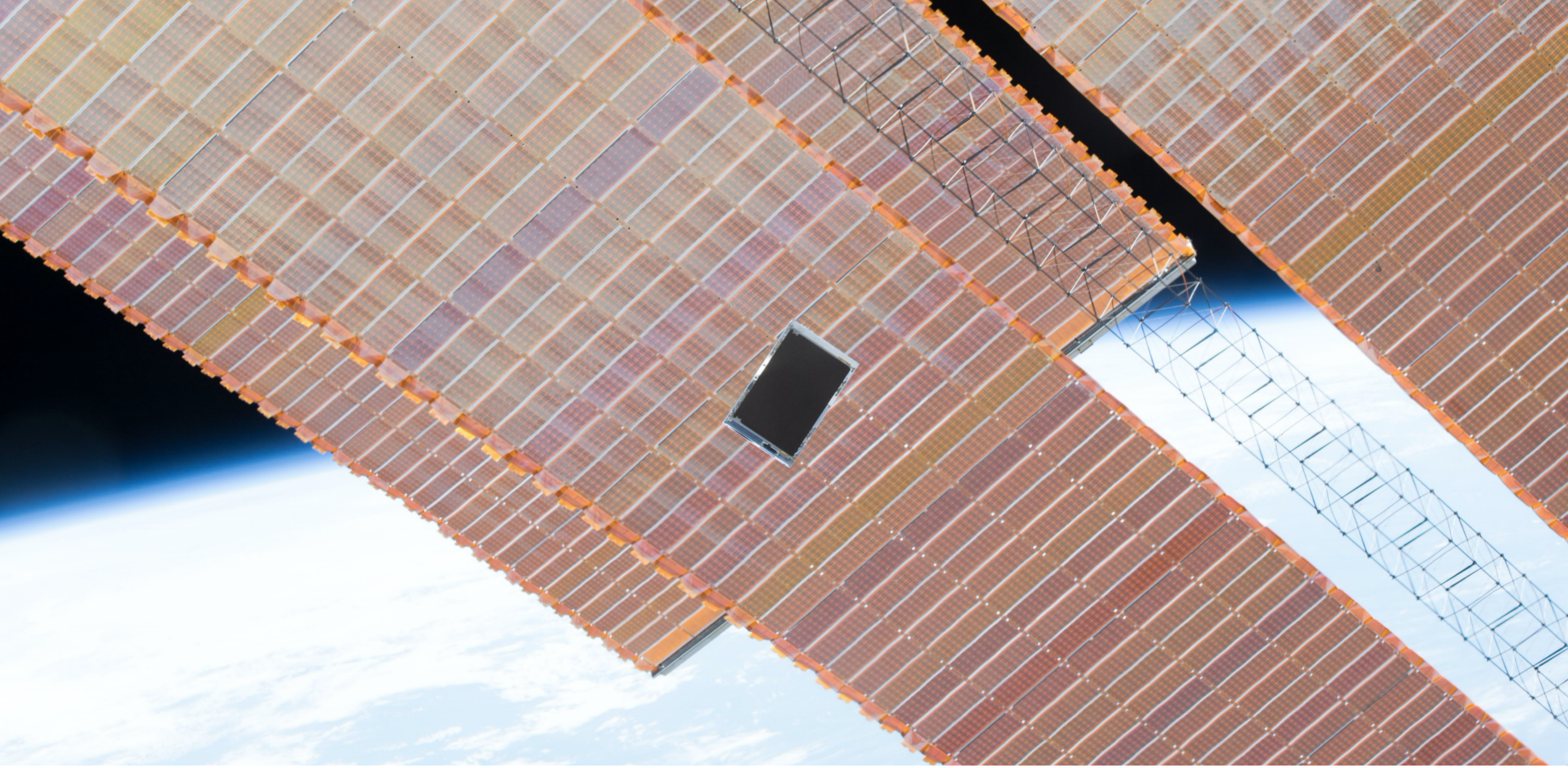

ASTERIA

Operations Demonstrates the Value of Combining the Mission Assurance and Fault Protection Roles on CubeSats

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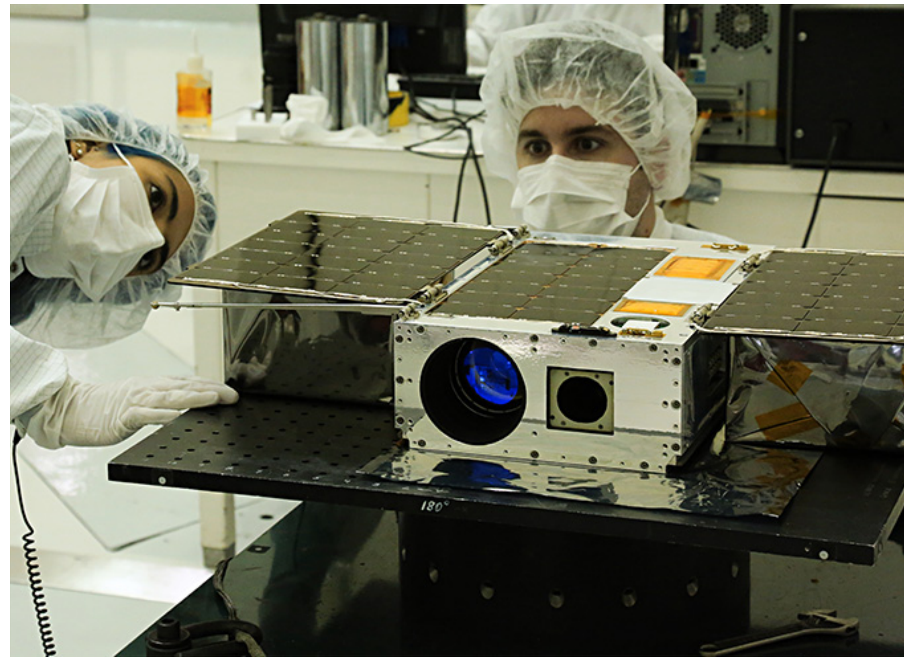
ASTERIA

Arcsecond Space Telescope Enabling Research In Astrophysics

Overview

- 6U CubeSat (approx. 10.2 kg, 11 x 24 x 37 cm^3)
- JPL and MIT collaboration
    - Sara Seager, PI
    - Built, tested, operated at JPL
- Funded through JPL's Phaeton Program for early career training plus MIT contributions to ops
- Launched to ISS in August 2017 on SpaceX CRS-12, deployed into orbit 3 months later by NanoRacks
- 300+ days of operation in space

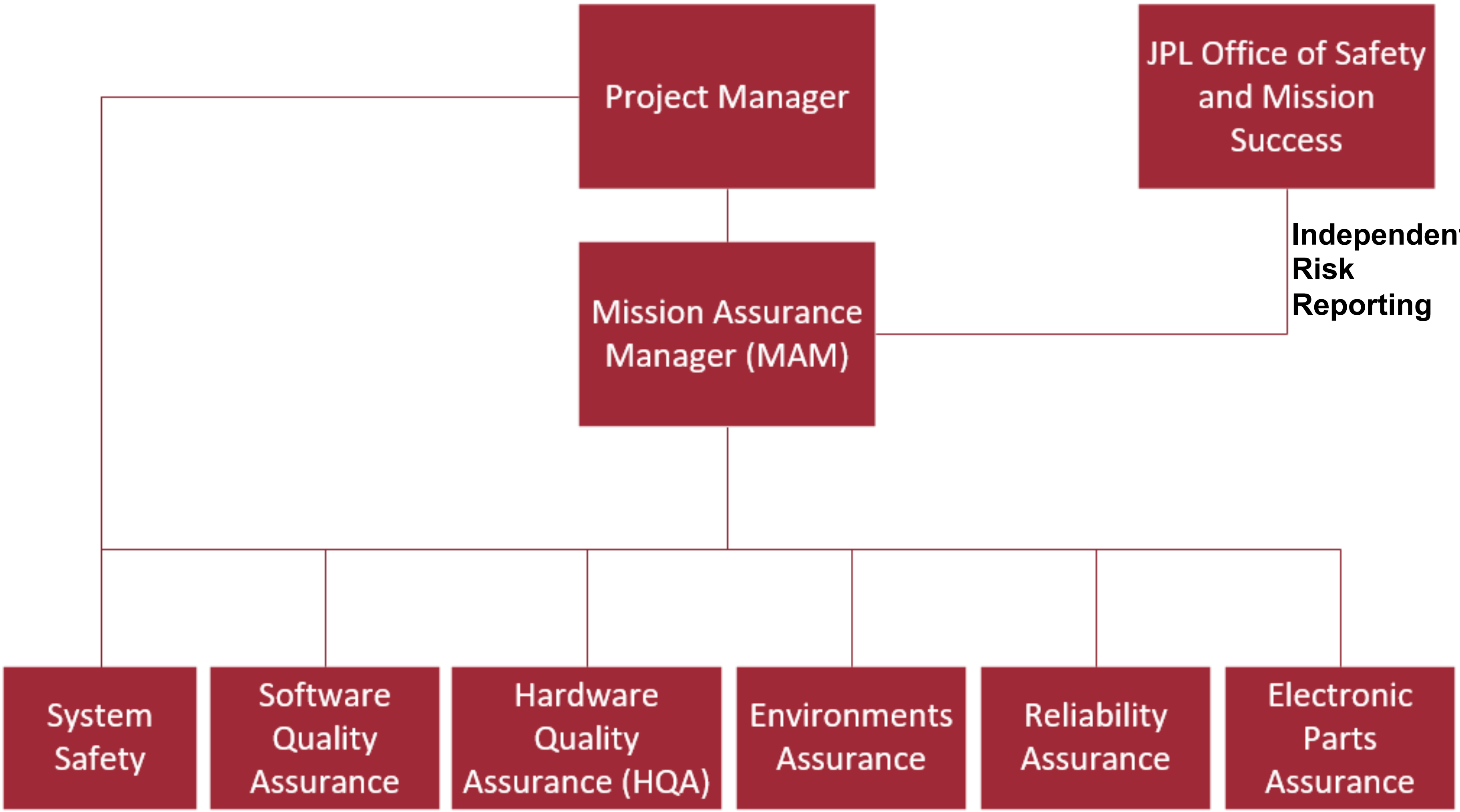


Mission Status

- Demonstrated subarcsecond pointing control and precision thermal control technologies in a nanosatellite platform
- ***Detected the known transit of 55 Cancri e***, offering a proof-of-concept for performing super-Earth exoplanet detections using a CubeSat platform
- Currently in extended mission searching for transiting exoplanets

Safety and Mission Assurance (SMA) Approach

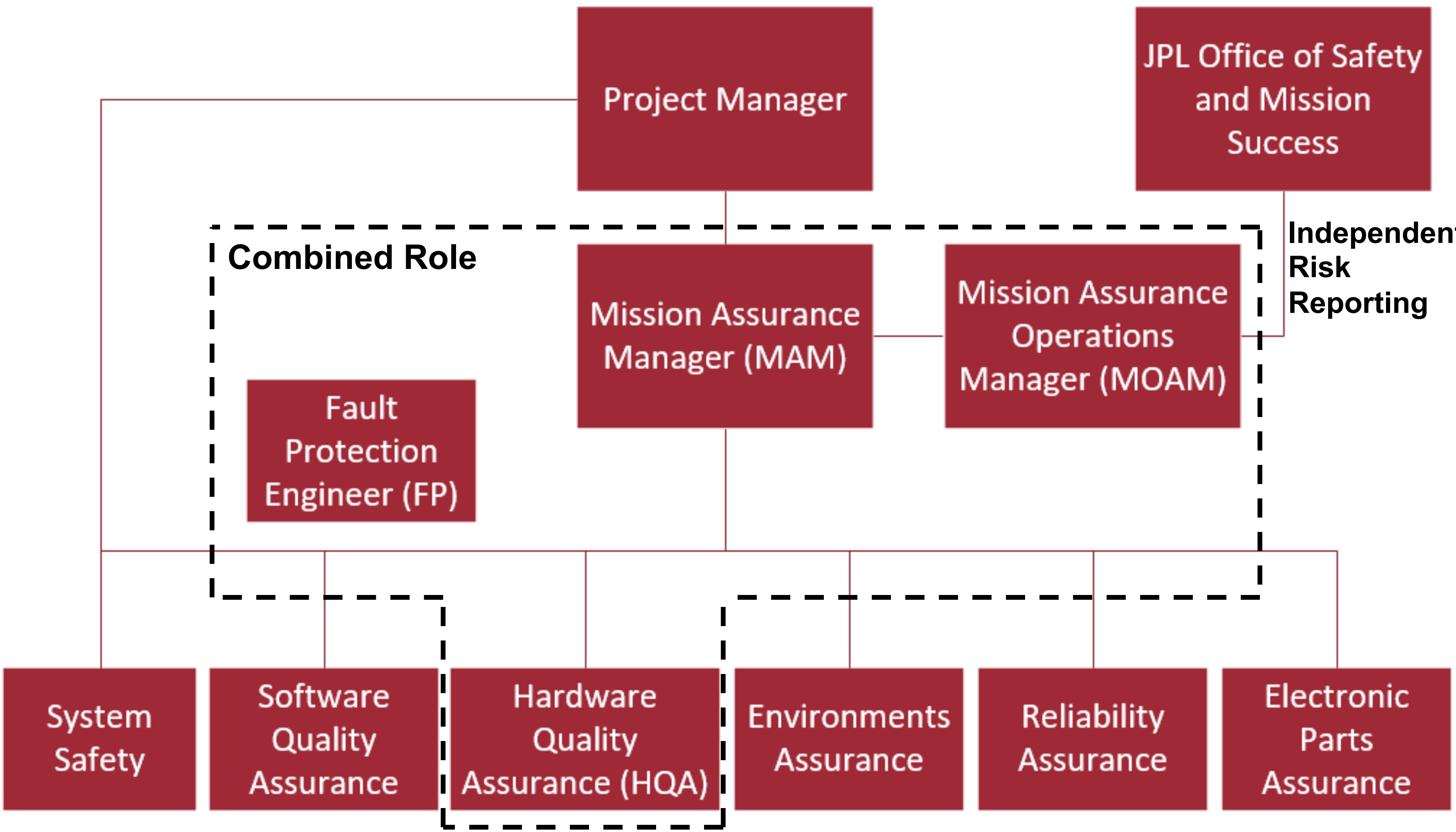
Large Project Standard: Separate Individual(s) for Each Role



Mission Operations Assurance Manager not shown (separate role in operations phase)

Safety and Mission Assurance (SMA) Approach

ASTERIA: Combined Roles to Scale for Small Team



Combined Roles on ASTERIA

Risk Management Example

HQA: Hardware Quality Assurance
FP: Fault Protection Engineer
MAM: Mission Assurance Manager
MOAM: Mission Operations Assurance Manager

HQA observes anomaly during system integration and testing

MAM records anomaly in JPL tool and evaluates corrective action

MOAM refers to anomaly list to troubleshoot in-flight anomalies

MAM adds residual risk to project risk list as appropriate

Other SMA disciplines also add inputs to risk list

FP identifies potential fault monitor to mitigate residual risk

FP runs thorough system testing (e.g., mission scenario tests)

Fault Protection Design

Monitors catch system-wide safety issues

Examples:
Low battery voltage*
ACS off-sun
Command loss
Sequence failure

Responses assert safe state

“Soft hammer” safe mode response powers off payload and commands ACS to point at sun

“Hard hammer” reset response power cycles all subsystems except EPS

EPS watchdog

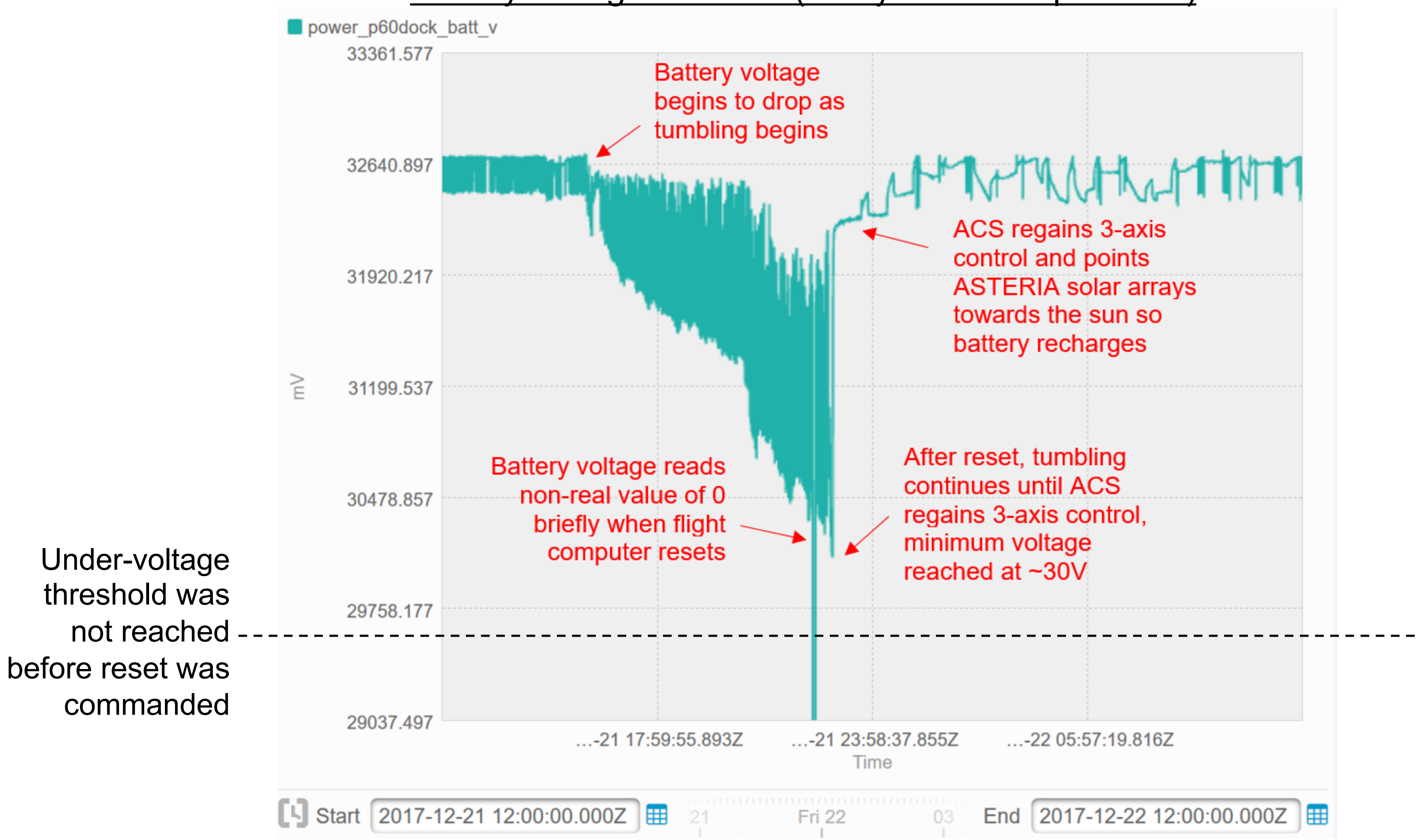
If FSW does not respond to health pings, EPS power cycles flight computer, which boots into Safe Mode

*At launch the response to this fault was the safe mode response, as testing and analysis had not identified a credible scenario where power cycling the ACS unit would provide greater benefit than risk…

Tumbling Anomaly and Commanded Reset

Motivation for Fault Protection Updates

Battery Voltage vs. Time (Analysis Tool: OpenMCT)



Fault Protection In-Flight Changes

Immediate Changes: No FSW Update

Before ACS Anomaly

Low battery voltage fault monitor called "soft-hammer" safe mode response

→

After ACS Anomaly

Low battery voltage fault monitor calls "hard-hammer" reset response

Later changes via FSW update

Before ACS Anomaly

Mode manager did not include a power cycle of ACS unit at safe mode entry

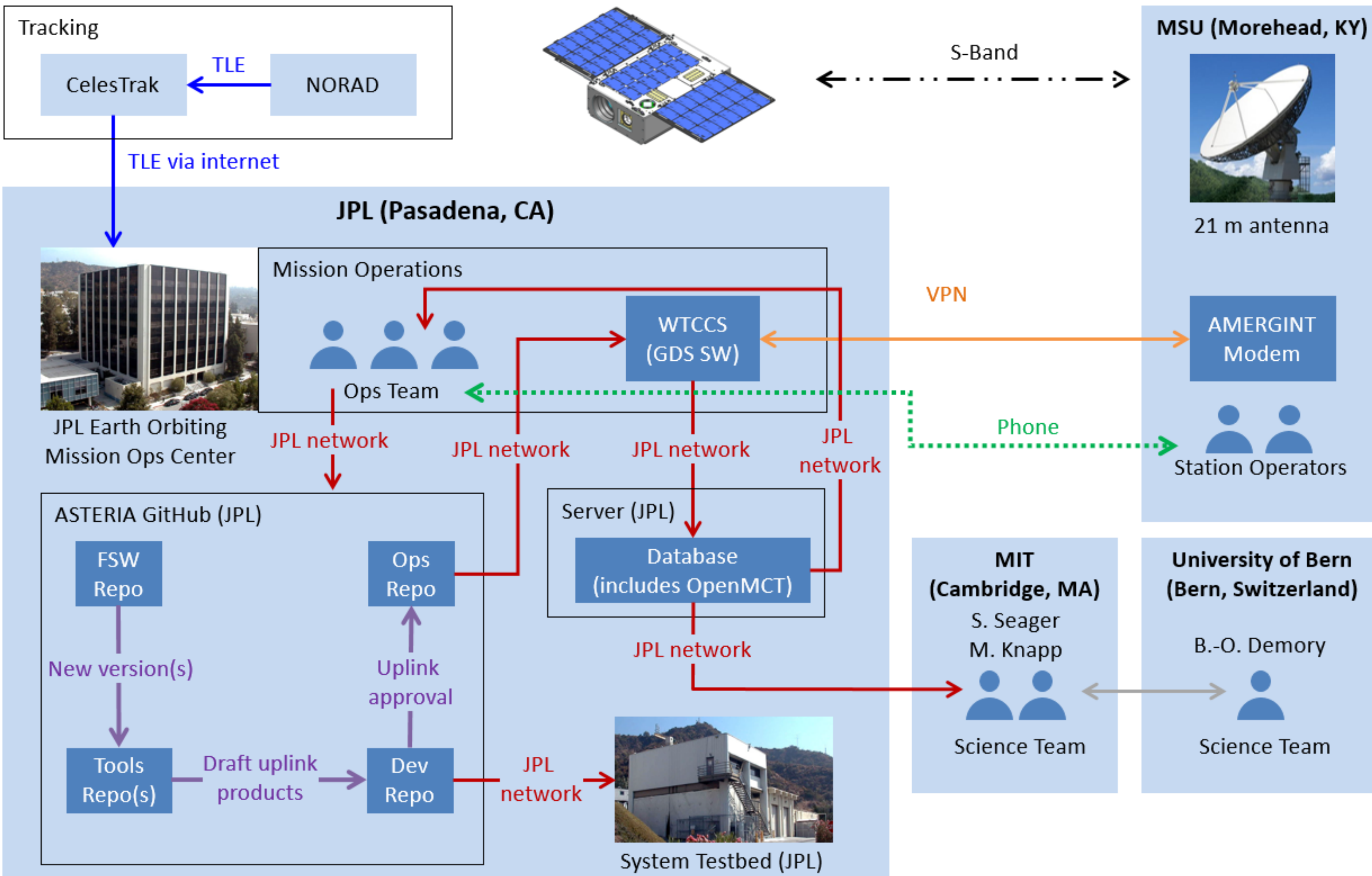
→

After ACS Anomaly

Updated mode manager to include power cycle of ACS unit upon safe mode entry

All changes were tested on the testbed per ASTERIA operations procedures

ASTERIA Operations Overview



Conclusions and Lessons Learned

CubeSat Mission Assurance:

- Limited funding on CubeSat mission requires:

A: Insight > Independence
One full-time individual acting as MAM also fills multiple other roles, ideally all related to risk mitigation.

or

B: Independence > Insight
One individual fills MAM role and maintains independence, but is not funded beyond a low-level of support.

- Solution A worked well on ASTERIA
  - Incorporation of independent reviews of mission assurance and fault protection approaches were key to mitigating a potential conflict of interest

CubeSat Fault Protection:

- Identify simple ***"catch-all" fault monitors*** and test them thoroughly
- Do not hesitate to implement a ***"hard-hammer" power-cycling response***
- Allow for ***in-flight fault protection updates*** without a FSW update

Acknowledgements

- **Extended ASTERIA development and operations teams**
- **JPL technical mentors and line organization**
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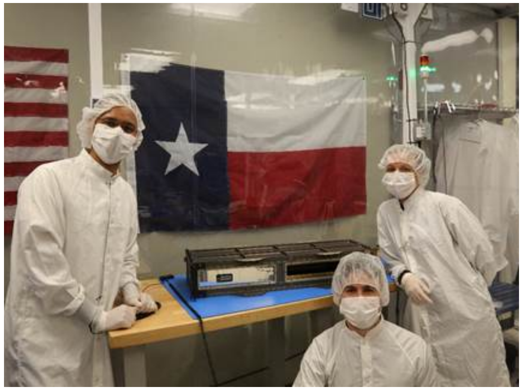
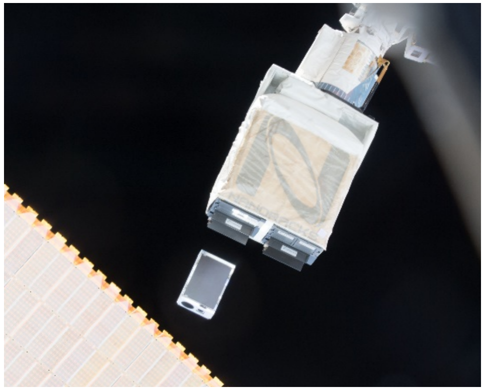
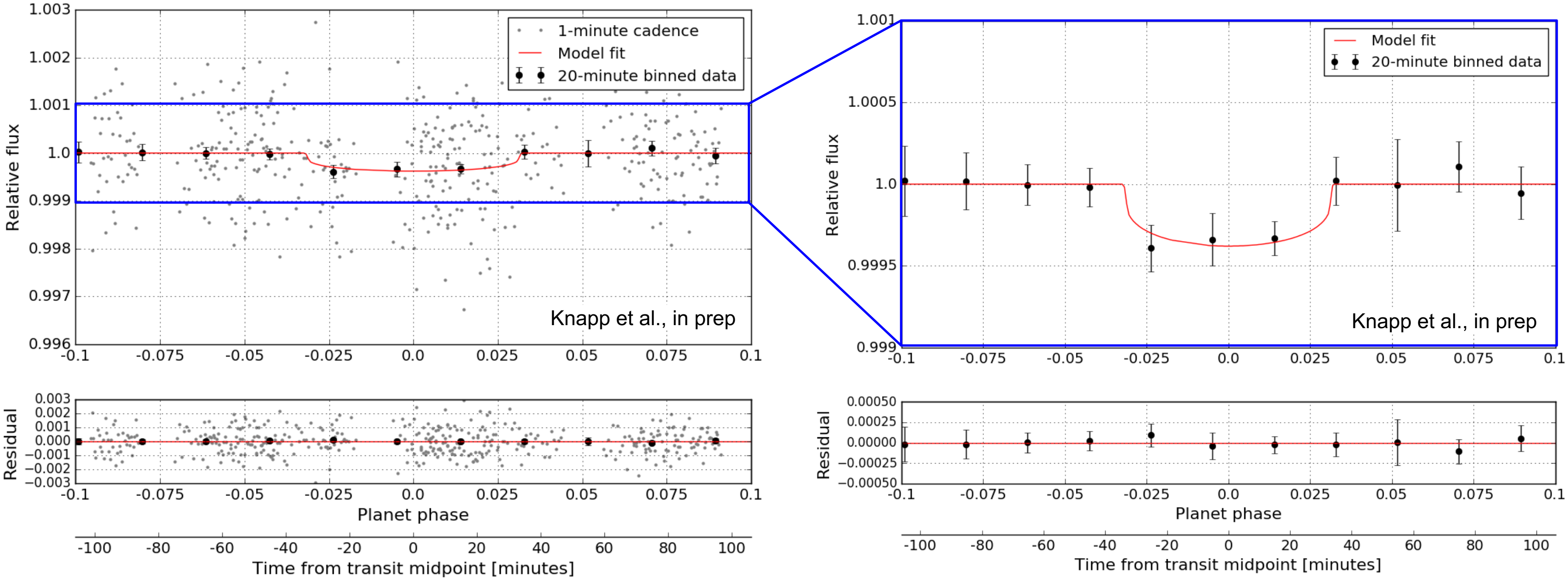
- **Sara Seager, Principal Investigator (Advisory)**, Massachusetts Institute of Technology
- **Brice-Olivier Demory**, University of Bern
- **Morehead State University team**

Questions?






55 Cancri e Detection

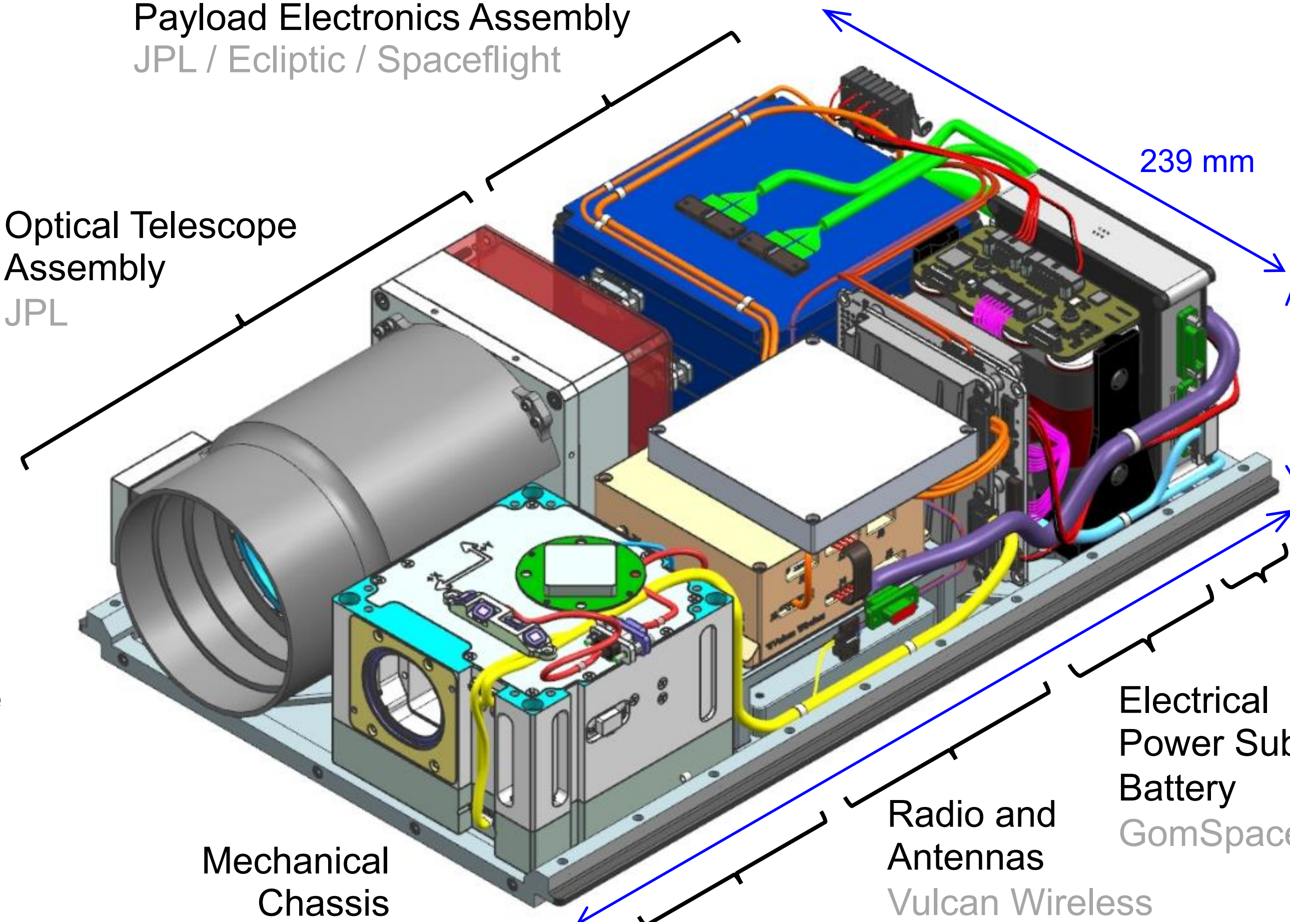


- 410 ppm transit observed at SNR=3
- $2R_E$ exoplanet around a V=5.95 Sun-like star
- The above plots contain 526 minutes of cumulative observation time, phase folded
- Photometric precision is 730 to 1140 ppm/min at V=5.95

Mission Assurance Approach

- **Hardware Quality Assurance (HQA):**
  - Inspections start at board assembly level (not part level)
  - Flow quality assurance requirements to vendors
  - Chair reviews for subsystems prior to system integration
  - Oversight during assembly and testing of flight system
- **Environments Assurance:**
  - Vibration test (per NanoRacks requirements) of flight system
  - Thermal vacuum test of flight system (with qual batteries)
  - Minimize effects due to electromagnetic interference and electrostatic discharge
- **Reliability Assurance:** focus on margin for electronic circuit use
- **Electronic Parts Assurance:** minimize radiation-induced single event effects
- **System Safety:**
  - NanoRacks safety requirements compliance evaluation
  - Conduct safety surveys of lab areas
- **Software Quality Assurance (SQA):**
  - Review initial flight software development plan
  - Support reviews of launch delivery software and in-flight software updates
- **Mission Operations Assurance Manager MOAM:**
  - Same individual as Mission Assurance Manager (MAM)
  - Focuses on risk against primary mission requirements
  - Manages in-flight anomaly reporting

Spacecraft



Flight Software
JPL (F Prime)

PCS Software
JPL

MOS Software
JPL / Alethium